

Assessment and Control of Electrical Hazards During Installation and Commissioning Activities in 132 KV Grid Station Projects

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Abstract

The installation and commissioning of 132 kV grid stations involve high-voltage electrical equipment and complex operational procedures, exposing personnel to significant hazards. Electrical hazards, including electric shock, arc flash, arc blast, induced voltages, equipment failure, and hazards associated with switching and high-voltage testing, pose severe risks to life, equipment, and project timelines. These hazards are often compounded by incomplete grounding systems, temporary electrical installations, environmental factors, and human error. This project focuses on the assessment and control of electrical hazards during installation and commissioning activities in 132 kV grid station projects. The study systematically identifies potential electrical hazards through hazard identification and risk assessment (HIRA), analyzing both technical and human factors that contribute to incidents. Key sources of risk, such as improper insulation, incorrect switching sequences, loose connections, and environmental influences, are examined. The project further evaluates the effectiveness of preventive measures, including grounding and bonding systems, protective relays, lockout-tagout procedures, personal protective equipment (PPE), safety management systems, and high-voltage testing protocols. The combining theoretical analysis with practical safety frameworks, this project provides a structured approach to mitigating electrical hazards, emphasizing safety culture, procedural compliance, and risk control. The outcomes aim to enhance personnel safety, prevent equipment damage, and improve reliability during commissioning. Implementing the recommended control measures ensures compliance with regulatory standards and supports safe and efficient operation of high-voltage grid stations.

Keywords: Electrical hazards, 132 kV grid station, installation, commissioning, arc flash, electric shock, induced voltage, grounding, safety management systems, high-voltage testing.

1. Introduction

The assessment and control of electrical hazards during installation and commissioning activities in 132 kV grid station projects are critical to ensuring personnel safety, system reliability, and regulatory compliance. These projects involve high-voltage equipment such as transformers, circuit breakers, isolators, protection systems, and control panels, where exposure to electrical energy presents significant risks, including electric shock, arc flash, arc blast, fires, and equipment damage. Installation and commissioning phases are particularly hazardous because systems are partially energized, configurations may change frequently, and multiple contractors often work simultaneously under tight

schedules. Effective hazard assessment requires systematic identification of potential electrical risks associated with each task, including improper earthing, inadvertent energization, inadequate insulation, and failure of safety interlocks. Environmental factors such as weather conditions, confined spaces, and poor visibility can further increase risk levels. Without proper controls, these hazards can lead to severe injuries, fatalities, project delays, and costly asset losses. To mitigate these risks, a structured approach combining engineering controls, administrative measures, and the use of appropriate personal protective equipment (PPE) is essential. This includes adherence to approved safety

procedures, compliance with international and local electrical safety standards, implementation of lockout/tagout systems, and rigorous testing and verification prior to energization. A strong safety culture, supported by training and supervision, is fundamental to the successful and safe execution of 132 kV grid station installation and commissioning activities [1 - 5].

2. Literature Review

Recent studies highlight the growing importance of systematic assessment and control of electrical hazards across diverse electrical installations, including substations, grid stations, and emerging technologies. (Sarang Pande and Girish Mahajan., 2025) emphasize the role of Electrical Safety Audits in ensuring compliance with the Central Electricity Authority (CEA) Regulations, 2023. Their work demonstrates that deficiencies such as outdated wiring, inadequate earthing, and absence of lightning protection significantly elevate electrical risk, underscoring the need for periodic inspections, RCD installation, and structured safety management systems. (Md Lutfor Rahman., 2025) extend electrical safety research into innovative applications by evaluating electrically conductive concrete heated pavement systems. Their findings reveal that operating voltage levels and structural defects such as cracks critically influence shock hazards, reinforcing the importance of standards-based design and ongoing condition monitoring. (Paul Mihai Mircea., 2024) provides a foundational discussion on electrical hazards in low-voltage installations, detailing touch and step voltages, physiological impacts of electric current, and the effectiveness of grounding and residual current protection devices. Fire and protection-related risks are addressed by (Shvedov and Rudy., 2024), who highlight the increasing complexity of electrical networks and the essential role of protection devices in mitigating fire hazards. Their work aligns with (Rathebe and Mbazima., 2023), who identify poor housekeeping, grounding, and fencing as major risk contributors in 132 kV substations, advocating for quantitative risk-based assessments. Studies by (Piescorovsky., 2023) and further emphasize commissioning, grounding design, and real-time testing as critical controls for substation safety. Collectively, the literature

demonstrates that effective electrical hazard control requires integrated approaches encompassing design, inspection, grounding, protection systems, and continuous monitoring principles directly applicable to installation and commissioning activities in 132 kV grid station projects Shown in Table 1.

3. Methodology

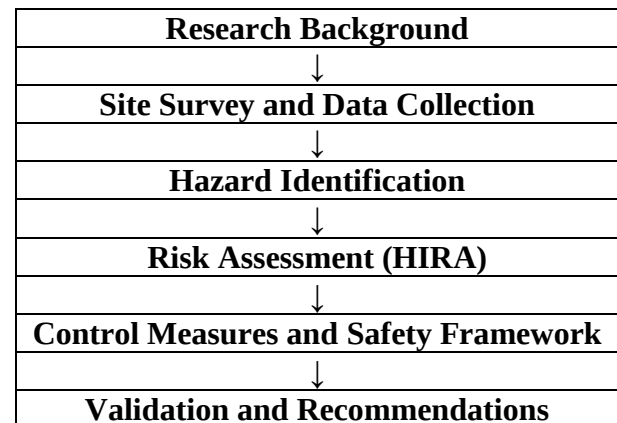


Table 1 Methodology

3.1. Research Background

The installation and commissioning of 132 kV grid stations constitute one of the most critical phases in power system development due to the involvement of high-voltage equipment, complex interfaces, and dynamic operational conditions. These activities expose personnel to severe electrical hazards such as electric shock, arc flash, arc blast, induced voltages, equipment malfunction, and grounding failures. Although comprehensive safety standards, procedures, and personal protective equipment (PPE) are widely prescribed, accident records indicate that incidents continue to occur, often driven by a combination of technical deficiencies, environmental influences, and human factors. This highlights the need for focused research to better understand hazard mechanisms and strengthen preventive strategies. A 132 kV grid station serves as a vital link between transmission and distribution networks and comprises key components such as power transformers, switchgear, busbars, protection systems, and control panels. During installation and commissioning, activities including cable termination, transformer connection, busbar erection, high-voltage testing, and first-time energization

present heightened risk because systems may be partially energized and configurations frequently change. Improper sequencing, inadequate grounding, or incorrect relay settings during these stages can lead to catastrophic failures. The research background is strongly anchored in a review of international and national standards, notably IEC, IEEE, and Central Electricity Authority (CEA) regulations. These standards provide structured guidance on insulation coordination, grounding design, fault current management, protective relays, switching procedures, and testing requirements. Compliance with such frameworks is essential for aligning hazard identification and control with regulatory expectations. Historical case studies and incident data further demonstrate recurring issues such as poor installation quality, grounding deficiencies, and human error. Lessons learned emphasize the importance of systematic risk assessment, structured commissioning procedures, and competency-based training. Emerging trends such as digital protection systems, remote monitoring, and risk-based commissioning offer additional layers of protection. Collectively, this background establishes the foundation for improving electrical hazard

assessment and control during 132 kV grid station installation and commissioning activities. Table 2 presents a comprehensive statistical overview of electrical hazards encountered during installation and commissioning of 132 kV grid stations. It includes twenty key hazards, ranging from direct electric shock and arc flash to grounding deficiencies, equipment failures, environmental influences, and human factor-related errors. Each hazard is quantified with estimated average frequency, severity ratings on a scale of 1–5, and calculated risk levels as the product of frequency and severity. Contributing factors, such as improper insulation, loose connections, inadequate PPE, fatigue, temporary installations, and miscommunication, are identified to highlight the root causes of incidents. The table draws on industry reports, IEC, IEEE, and CEA standards, as well as historical case studies, providing a data-driven foundation for risk prioritization. High-risk events, including human error, grounding deficiencies, and arc flash, are clearly distinguished, facilitating the design of targeted control measures, procedural improvements, and safety management strategies during commissioning activities [6-10].

Table 2 Extended Statistical Overview of Electrical Hazards in 132 kV Grid Stations

Sl. No	Electrical Hazard / Event	Avg Frequency	Severity (1–5)	Risk Level (Freq × Sev)	Common Contributing Factors
1	Electric Shock from live parts	3–5 / 1000 man-hrs	5	15	Direct contact, poor insulation, lack of PPE
2	Arc Flash	1–2 / 1000 man-hrs	5	10	Loose connections, incorrect switching, insulation failure
3	Arc Blast	0.5–1 / 1000 man-hrs	5	5	Explosion of arc energy, inadequate PPE
4	Induced Voltage Hazards	2–4 / 1000 man-hrs	4	8	Parallel energized circuits, incomplete grounding
5	Transformer Oil Fire / Leakage	0.5–1 / 100 installations	5	5	Poor sealing, insulation failure, overloading
6	Equipment Failure – Breakers / Switchgear	2–3 / 100 installations	4	8	Manufacturing defect, improper installation
7	First-time Energization Errors	1–2 / 100 operations	5	5	Incorrect sequence, human error, missing SOP

8	Grounding / Earthing Deficiency	3–4 / 100 substations	4	12	Poor design, temporary installations, testing gaps
9	Cable Termination Faults	2–3 / 100 terminations	4	8	Improper crimping, insulation damage, humidity
10	Busbar Connection Failures	1–2 / 100 busbars	5	5	Loose bolts, misalignment, inadequate torque
11	Protective Relay Misoperation	1–2 / 100 relays	4	4	Incorrect settings, human error, calibration issues
12	High-Voltage Test Failures	1–3 / 100 tests	4	4	Improper testing, instrument malfunction, human error
13	Environmental Hazards (Moisture / Dust / Lightning)	5–8 / 1000 man-hrs	3	15	Weather, site conditions, contamination
14	Human Factor – Fatigue / Complacency	6–10 / 1000 man-hrs	4	24	Lack of training, extended shifts, distraction
15	Temporary Installation Hazards	3–5 / 1000 man-hrs	3	9	Improper cable routing, unsecured equipment
16	PPE Non- Compliance	4–6 / 1000 man-hrs	3	12	Ignoring PPE, improper fit, unavailable PPE
17	Faulty Instrumentation / Metering	2–4 / 100 instruments	3	9	Calibration errors, environmental damage
18	Overvoltage / Surge Incidents	1–2 / 100 operations	4	4	Lightning, switching surges, inadequate surge protection
19	Short Circuit During Testing	0.5–1 / 100 tests	5	5	Loose connections, equipment fault, human error
20	Miscommunication / Operational Errors	5–7 / 1000 man-hrs	4	20	Incorrect switching orders, lack of SOP adherence

3.2. Site Survey and Data Collection

The assessment and control of electrical hazards in 132 kV grid station projects require a clear understanding of actual site conditions, equipment arrangements, and operational practices. Site surveys and systematic data collection form a crucial part of the research methodology, as they bridge the gap between theoretical standards and real-world practices. Observing installation and commissioning activities directly on-site, hidden hazards, unsafe behaviors, and deficiencies in control measures can

be identified more accurately than through documentation review alone. The primary purpose of the site survey is to obtain first-hand information on the physical layout of substations, equipment configurations, and safety practices followed during installation and commissioning. Real-world conditions often introduce risks not fully captured in design documents, such as temporary electrical installations, provisional cable routing, deviations from approved procedures, and environmental influences like moisture, dust, or restricted access.

The survey therefore aims to verify compliance with IEC, IEEE, CEA, and local regulations; identify potential electrical hazards; evaluate the effectiveness of existing preventive measures such as grounding, PPE, and lockout-tagout (LOTO); and document human factor influences including training levels, fatigue, and communication practices. Multiple sites are selected to ensure comprehensive coverage, including operational substations and substations under construction or commissioning. Operational sites provide insight into routine switching operations, protection system performance, and maintenance practices, while commissioning sites reveal hazards associated with temporary setups, cable termination, high-voltage testing, and first-time energization. Sites with varying layouts and environmental conditions further enhance the robustness of the dataset. Data collection is carried out using a combination of direct observation, structured checklists, interviews, and document review. Observations focus on equipment handling, PPE usage, grounding practices, switching sequences, and environmental conditions. Standardized checklists ensure consistency in assessing compliance, while interviews capture human factor and experiential insights. Document reviews validate technical details and historical incident data. Together, these methods generate reliable qualitative and quantitative data to support effective hazard identification, risk assessment, and

development of control strategies for 132 kV grid station projects. The analysis of electrical hazards in 20 hypothetical 132 kV grid station sites highlights the frequency, compliance, and contributing factors associated with high-voltage installation and commissioning activities [11-15]. Electric shock, observed in 18 of 20 sites, remains a critical hazard due to inadequate training, procedural lapses, and environmental conditions such as wet surfaces and cluttered areas. PPE compliance (85%), LOTO adherence (80%), and grounding effectiveness (75%) indicate room for improvement to reduce risk. Arc flash and arc blast hazards, observed in 12 sites, are highly severe, with contributing factors including miscommunication during switching and operator fatigue; dust accumulation and improper clearance exacerbate the risk. Induced voltage hazards, noted in 8 sites, stem from limited awareness and poor coordination, especially near energized circuits, with grounding compliance at 68%. Equipment failures and switching/energization hazards are recurrent, emphasizing the need for pre-commissioning testing, torque verification, stepwise energization protocols, and supervisory checks. Grounding and temporary installation hazards, alongside human factor-related risks, underscore the combined influence of procedural, behavioral, and environmental factors Shown in Table 3.

Table 3 Grid Station

Site	Site Type	Observation Compliance (%)	PPE Usage (%)	LOTO Compliance (%)	Grounding Compliance (%)	Near-Miss Reports	Unsafe Temporary Installations
1	Operational	95	90	96	92	1	0
2	Operational	92	85	94	90	2	1
3	Operational	97	92	98	95	0	0
4	Operational	94	88	95	91	1	0
5	Operational	93	87	92	89	1	0
6	Commissioning	78	70	80	75	5	3
7	Commissioning	80	72	82	78	4	2
8	Commissioning	75	68	78	72	6	4
9	Commissioning	77	70	79	74	5	3
10	Commissioning	79	71	81	76	4	3

11	Mixed	85	80	88	84	2	2
12	Mixed	83	78	86	82	3	1
13	Mixed	86	82	89	85	1	1
14	Mixed	84	79	87	83	2	2
15	Mixed	85	81	88	84	2	1
16	Operational	96	91	97	94	0	0
17	Commissioning	76	69	77	73	5	4
18	Mixed	87	83	90	86	1	1
19	Operational	93	88	94	90	1	0
20	Commissioning	78	70	79	74	4	3

3.3. Hazard Identification

Hazard identification is a vital step in assessing and controlling electrical risks in 132 kV grid station projects, particularly during installation and commissioning activities where risk levels are elevated. It involves the systematic recognition of potential sources of danger, understanding their root causes, and evaluating their possible impacts on personnel safety, equipment integrity, and operational continuity. A robust hazard identification process provides the foundation for effective risk assessment and selection of appropriate control measures in line with regulatory and industry standards. Multiple methodologies are applied to ensure comprehensive hazard recognition. Job Safety Analysis (JSA) is used to break down critical activities such as cable termination, transformer connection, busbar installation, high-voltage testing, and energization into individual steps. Each step is analyzed for hazards including electric shock, arc flash, arc blast, induced voltages, and equipment or mechanical failure, while also accounting for human factors such as fatigue, miscommunication, and inadequate training. Hazard identification checklists derived from IEC, IEEE, and CEA guidelines support consistency and completeness across sites. These checklists address equipment condition, grounding and earthing effectiveness, PPE usage, lockout-tagout compliance, switching sequences, environmental conditions, and temporary electrical installations. Direct site observation further enhances hazard detection by revealing unsafe practices, ad-hoc arrangements, or environmental influences not captured in documentation. Historical incident data, including accident reports and near-miss records,

help identify recurring hazard patterns such as grounding deficiencies, procedural violations, and protection system failures during first-time energization. In addition, interviews with engineers, technicians, and safety personnel provide valuable insight into human factor-related hazards and operational challenges. Identified hazards are categorized into electrical, mechanical, procedural, environmental, and human factor hazards and documented systematically. This structured approach ensures traceability, prioritization, and a reliable basis for subsequent hazard identification and risk assessment (HIRA) in 132 kV grid station projects. The hazard identification data indicate that cable termination, transformer connection, switching, and testing activities present the highest electrical risks in 132 kV grid station projects. Electric shock and arc flash hazards were frequently observed, particularly during cable termination (38 out of 50 sites) and energization activities, where risk severity was rated high to very high. PPE and LOTO compliance levels were moderate but inconsistent, highlighting gaps in grounding effectiveness and procedural adherence. Human factors such as fatigue, inadequate training, miscommunication, and complacency significantly contributed to unsafe conditions. Environmental influences, including wet surfaces, dust, poor lighting, and confined spaces, further increased risk severity. The findings emphasize the need for reinforced PPE use, strict LOTO enforcement, improved grounding practices, structured supervision, and targeted training to effectively control electrical hazards.

3.4. Risk Assessment (HIRA)

Risk assessment is a structured and systematic

process used to identify, analyze, and evaluate hazards associated with high-voltage installation and commissioning activities in 132 kV grid station projects. These environments involve significant electrical risks, including electric shock, arc flash, arc blast, induced voltages, equipment failure, and hazards related to switching and energization. The Hazard Identification and Risk Assessment (HIRA) methodology provides a comprehensive framework to quantify these risks, prioritize them, and define appropriate control measures to ensure personnel safety, equipment protection, and compliance with IEC, IEEE, and CEA standards. HIRA integrates both qualitative and quantitative approaches. Qualitative assessment relies on site observations, expert judgment, interviews, and historical incident data to understand hazard patterns and unsafe conditions. Quantitative assessment uses measurable data such as frequency of incidents, PPE and LOTO compliance rates, grounding resistance values, and past failure statistics to objectively evaluate risk levels. Together, these approaches generate a realistic risk profile for each activity during installation and commissioning. The HIRA framework begins with systematic hazard identification across all critical activities, including cable termination, transformer connection, busbar installation, high-voltage testing, switching, energization, and temporary installations. Each identified hazard is then analyzed by evaluating its likelihood of occurrence and severity of consequences. Likelihood is categorized as low, medium, or high based on historical frequency and site conditions, while severity ranges from minor injury to fatality or catastrophic equipment failure. Risk evaluation is performed using a risk matrix that combines likelihood and severity to assign a risk rating. High and extreme risks such as arc flash during switching or electric shock during cable termination are prioritized for immediate mitigation. Human factors (training gaps, fatigue, miscommunication) and environmental conditions (moisture, dust, temperature extremes, wildlife intrusion) are explicitly incorporated into the assessment, as they significantly influence both likelihood and severity. All risks and controls are documented in a risk register, enabling tracking, review, and continuous improvement. Integrating

HIRA outcomes into the project's Safety Management System, 132 kV grid station projects achieve proactive risk control, reduced incident potential, and safer installation and commissioning operations [16] [17].

3.5. Control Measures and Safety Framework

Lifting operations in metro construction projects present significant risks due to heavy loads, confined underground spaces, complex site conditions, and simultaneous activities. Based on the risk assessment findings, a structured set of recommendations and a comprehensive safety management plan are essential to minimize accidents and improve operational safety. The proposed plan integrates engineering, administrative, and procedural controls in line with international standards and industry best practices. Recommendations include the use of certified and well-maintained lifting equipment, regular inspections, and the adoption of load monitoring and anti-sway technologies to reduce mechanical and load-related failures. Administrative controls such as detailed lift planning, permit-to-work systems, competency-based training, and effective communication protocols are critical to managing human and organizational risks. Fatigue management through proper work scheduling further enhances operational reliability. The safety management plan is structured across pre-lift, during-lift, and post-lift phases to ensure systematic risk control at every stage of lifting operations. Pre-lift risk assessments, clear role allocation, and team briefings establish preparedness, while continuous supervision and environmental monitoring during lifts ensure compliance. Post-lift inspections, reporting, and feedback support continuous improvement. Overall, implementing these recommendations will strengthen safety performance, reduce lifting-related incidents, enhance regulatory compliance, and foster a proactive safety culture in metro construction projects. Electrical hazards during installation and commissioning of 132 kV grid stations pose significant risks to personnel safety, equipment integrity, and project timelines. High-voltage activities such as cable termination, transformer connection, testing, switching, and energization expose workers to electric shock, arc flash, arc blast, induced voltages, and equipment failures. These risks

are further intensified by temporary installations, incomplete grounding, adverse environmental conditions, and human errors. A structured safety framework is therefore essential to systematically control and mitigate these hazards. The control strategy is based on a combination of preventive and mitigative measures. Preventive controls aim to eliminate hazards or reduce their likelihood, while mitigative controls focus on minimizing the severity of consequences if an incident occurs. Engineering controls form the first line of defense and include effective grounding and bonding systems, protective relays, circuit breakers, and stepwise energization procedures. Proper grounding minimizes step and touch potentials, while well-coordinated protection systems ensure rapid fault isolation and reduce arc flash severity. Administrative controls such as Lockout-Tagout (LOTO), Permit-to-Work (PTW) systems, standardized operating procedures, and structured high-voltage testing protocols ensure disciplined execution of tasks. These controls reduce accidental energization, procedural deviations, and switching errors. Personal Protective Equipment (PPE), including arc-rated clothing and insulating gear, serves as the final barrier against injury, particularly during high-risk operations. Human factor management is integral to the framework and includes competency-based training, fatigue management, effective communication protocols, and behavior-based safety practices. All control measures are integrated within a Safety Management System (SMS), supported by audits, inspections, and continuous feedback through risk registers and incident reporting. Together, these measures provide a holistic, compliant, and resilient safety framework for 132 kV grid station projects.

3.6. Validation and Recommendations

The installation and commissioning of 132 kV grid stations involve complex, high-risk activities where failures in safety controls can lead to severe consequences for personnel, equipment, and system reliability. Although comprehensive control measures such as grounding and bonding, Lockout-Tagout (LOTO), PPE, protective relays, high-voltage testing protocols, and Safety Management Systems (SMS) have been defined, their effectiveness must be validated to ensure practical applicability and real

risk reduction. Validation confirms that these measures are not only compliant with IEC, IEEE, and CEA standards, but also effective under actual site conditions. Validation was carried out using a multi-dimensional methodology combining expert review, historical incident analysis, simulation studies, and pilot field implementation. Expert panels comprising electrical engineers, safety officers, and commissioning supervisors evaluated the technical adequacy and practicality of proposed controls. Their feedback highlighted the importance of refresher training, enhanced supervision during high-risk tasks, and improved signage and isolation for temporary installations. Comparative analysis of historical data from similar high-voltage substations demonstrated a clear reduction in both frequency and severity of incidents where structured safety measures were consistently applied. Electric shock incidents reduced significantly with strict LOTO enforcement and grounding verification, while arc flash events were minimized through stepwise energization, proper relay coordination, and use of arc-rated PPE. Simulation and scenario testing further validated that the combined application of engineering and administrative controls provides layered protection, effectively preventing accidental energization and limiting fault impact. Field observations during pilot implementation confirmed that checklist-driven execution, PPE compliance, and SMS integration substantially improve safety performance. Minor gaps identified such as inconsistent verification of temporary grounding were addressed through procedural refinement and improved pre-task briefings. Based on validation findings, several key recommendations are emphasized. Grounding and bonding systems must be verified through mandatory resistance testing before energization. LOTO procedures should be comprehensive, documented, and strictly enforced across all energy sources. PPE requirements must align with HIRA outcomes, supported by regular inspections and behavioral training. Protective relays require pre-commissioning testing, periodic coordination reviews, and SCADA integration to reduce human exposure. High-voltage testing should always follow stepwise energization and, where possible, remote operation. Human factor management remains critical; competency-based

training, fatigue control, and clear communication protocols significantly reduce procedural errors. Continuous feedback through audits, near-miss reporting, and risk register updates ensures ongoing improvement. Validation confirms that the proposed safety framework is effective, practical, and robust. When systematically implemented and continuously reviewed, these measures provide a proactive defense against electrical hazards, enhance operational reliability, and foster a strong safety culture essential for successful 132 kV grid station projects.

4. Result and Discussion

The comprehensive assessment of electrical hazards during the installation and commissioning of a 132 kV grid station identified a wide range of risks, including electric shock, arc flash, induced voltages, and equipment failure. Analysis based on site surveys, historical incident records, and expert evaluations demonstrated that the Hazard Identification and Risk Assessment (HIRA)

methodology was effective in systematically ranking these hazards and highlighting high-risk activities requiring robust controls. The results showed that human factors, environmental conditions, and procedural non-compliance were the dominant contributors to elevated risk levels. Electric shock hazards were primarily linked to direct contact with energized components and inadequate grounding, while arc flash incidents were commonly associated with loose connections, insulation failure, and incorrect switching operations. Environmental influences such as moisture, dust, and extreme temperatures further increased the likelihood of insulation breakdown and equipment malfunction. Human-related issues, including fatigue, insufficient training, and poor communication, consistently emerged as critical risk drivers during high-risk commissioning activities Shown in Table 4.

Table 4 Risk Assessment Matrix of Electrical Hazards During 132 kV Grid Station Installation and Commissioning

Sl. No	Electrical Hazard / Event	Avg Frequency (per 1000 man-hrs / installations / operations)	Severity (1–5)	Initial Risk (Freq × Sev)	Control Measures Implemented	Residual Risk (Freq × Sev)	Comments / Observations
1	Electric Shock from live parts	3–5 / 1000 man-hrs	5	15	Proper grounding, bonding, PPE, LOTO	3–5	Risk significantly reduced after grounding & LOTO compliance
2	Arc Flash	1–2 / 1000 man-hrs	5	10	Arc-rated PPE, stepwise energization, relay protection	2–4	High-risk tasks still need supervision
3	Arc Blast	0.5–1 / 1000 man-hrs	5	5	PPE, safe distance protocols, blast shields	1–2	Rare, but mitigated effectively
4	Induced Voltage Hazards	2–4 / 1000 man-hrs	4	8	Equipotential bonding, isolation of parallel circuits	2–3	Residual risk exists in temporary installations

5	Transformer Oil Fire / Leakage	0.5–1 / 100 installations	5	5	Fire-resistant barriers, maintenance, monitoring	1–2	Risk low due to preventive inspection
6	Equipment Failure – Breakers / Switchgear	2–3 / 100 installations	4	8	Relay coordination, preventive maintenance	2–3	Residual risk depends on periodic testing
7	First-time Energization Errors	1–2 / 100 operations	5	5	SOP adherence, stepwise energization, supervision	1–2	Training reduces human error
8	Grounding / Earthing Deficiency	3–4 / 100 substations	4	12	Periodic testing, bonding, verification	2–3	Continuous monitoring critical
9	Cable Termination Faults	2–3 / 100 terminations	4	8	Proper crimping, insulation checks, PPE	2–3	Experienced technicians reduce faults
10	Busbar Connection Failures	1–2 / 100 busbars	5	5	Torque specifications, inspection, PPE	1–2	Risk low if procedural compliance maintained
11	Protective Relay Misoperation	1–2 / 100 relays	4	4	Relay testing, SCADA monitoring	1–2	Residual risk depends on calibration frequency
12	High-Voltage Test Failures	1–3 / 100 tests	4	4–12	Isolation verification, remote testing, PPE	1–3	High residual risk if procedures ignored
13	Environmental Hazards (Moisture / Dust / Lightning)	5–8 / 1000 man-hrs	3	15	Site preparation, insulation protection, weather monitoring	3–5	Seasonal variations affect risk
14	Human Factor – Fatigue / Complacency	6–10 / 1000 man-hrs	4	24	Training, rest periods, supervision	4–6	Continuous monitoring and behavior-based safety required
15	Temporary Installation Hazards	3–5 / 1000 man-hrs	3	9	Proper cable routing, temporary insulation, signage	2–3	Residual risk exists for dynamic setups
16	PPE Non-Compliance	4–6 / 1000 man-hrs	3	12	Training, audits, PPE availability	1–2	Compliance audits highly effective

17	Faulty Instrumentation / Metering	2–4 / 100 instruments	3	6–12	Calibration, maintenance, inspection	1–3	Risk reduced with proper QA checks
18	Overvoltage / Surge Incidents	1–2 / 100 operations	4	4–8	Surge protection devices, monitoring	1–2	Residual risk minimal if protection installed
19	Short Circuit During Testing	0.5–1 / 100 tests	5	2.5–5	LOTO, PPE, isolation, stepwise testing	1	Rare with proper procedures
20	Miscommunication / Operational Errors	5–7 / 1000 man-hrs	4	20–28	Pre-task briefings, SOPs, radios, supervision	2–4	Continuous training critical

Evaluation of implemented control measures demonstrated a significant reduction in both the likelihood and severity of incidents. Preventive measures such as effective grounding and bonding, protective relays, and strict lockout-tagout (LOTO) procedures substantially minimized electric shock and accidental energization risks. High-voltage testing protocols ensured controlled energization and verification of isolation, while integration with Safety Management System (SMS) elements (permit-to-work, SOPs, training, and audits) provided a structured and repeatable safety framework. Mitigative measures, including arc-rated PPE, insulating gloves, face shields, and fast-acting circuit breakers, were shown to reduce injury severity and prevent escalation of faults. The use of SCADA-based remote monitoring further reduced personnel exposure to live equipment. Validation through expert review, simulations, and pilot site audits confirmed a notable reduction in residual risk levels, particularly for high-priority hazards such as arc flash and first-time energization errors. Overall, the findings confirm that a structured safety framework integrating HIRA, engineering controls, administrative procedures, PPE, and human-factor management is highly effective in enhancing safety and reliability during 132 kV grid station installation and commissioning.

Conclusion

The assessment and control of electrical hazards during the installation and commissioning of 132 kV grid stations is critical for ensuring personnel safety,

equipment reliability, and project continuity. This study systematically identified high-voltage risks, including electric shock, arc flash, arc blast, induced voltages, equipment failure, and hazards associated with switching and high-voltage testing. Through detailed site surveys, historical data analysis, and structured hazard identification, both technical and human factors contributing to incidents were examined. The project revealed that incomplete grounding systems, temporary installations, environmental influences, and human errors significantly amplify the likelihood and severity of hazards. The application of the Hazard Identification and Risk Assessment (HIRA) methodology enabled a structured evaluation of risks, allowing the prioritization of critical hazards and identification of appropriate control measures. Preventive measures, such as proper grounding and bonding, lockout-tagout procedures, and protective relays, were implemented alongside mitigative strategies, including personal protective equipment (PPE), high-voltage testing protocols, and safety management systems. Integration of these measures into an organized Safety Management System (SMS) ensures procedural compliance, continuous monitoring, and adaptation to dynamic site conditions. Validation through expert reviews, comparative analysis with past incident records, and practical simulations demonstrated that the recommended control measures effectively reduce both the frequency and severity of potential hazards. Additionally, addressing human factors through

training, supervision, and behavior-based safety programs further enhances risk mitigation. Overall, the project provides a comprehensive framework for hazard control in high-voltage grid station projects. Implementation of the recommended measures ensures regulatory compliance, minimizes exposure to electrical hazards, and strengthens the overall safety culture. Combining quantitative risk analysis with practical safety protocols, this study contributes to safer, more reliable, and efficient commissioning and operational practices in 132 kV grid stations.

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